# Pond Aquaculture in Waterlogged Salt-Alkali Land

# 11

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Salt-alkali land refers to the soil with high levels of salt content or/and alkalinity, which interferes with the normal growth of crops. There are 800 million $hm^2$ of salt-alkali land (mainly distributed in the Asia-Pacific region) in the world, accounting for about 6% of the global land area and 20% of the agricultural land. More than 100 countries in the world embrace salt-alkali land and the ones with large salt-alkali land areas are Russia, India, Pakistan, China, and so on. Every day for over 20 years, an average of 2000 ha of irrigated land in arid and semiarid areas in 75 countries have been degraded by salt. The sea level rise caused by global climate change may also accelerate land salinization (Dagar et al. 2019). Therefore, how to efficiently and sustainably exploit these salt-alkali land resources is one of the important issues that human beings face.

About 2000 BC, farmers in Lower Egypt started to use a land reclamation technology which is highly productive and still be used today (Fagan 2017). During the spring they dug large ponds in saline soil and flooded them with freshwater for 2 weeks. The lower salinity of the standing water forced the saline groundwater downward. They drained the ponds, repeated the process, and discarded the second flooding as well. Then they filled the pond with 30 cm of water and stocked it with mullet fingerlings caught from the ocean. Nowadays, the integrated utilization of salt-alkali land by aquaculture and agriculture is one of the effective technologies to exploit salt-alkali land resources. This chapter will briefly introduce the pond-based aquaculture-agriculture system on salt-alkali land, tolerance of farmed aquatic animals to saline and alkaline water, water quality control of the ponds, etc. In this chapter, salinity refers to the total concentrations of all ions in seawater only; as for

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the total concentrations of all ions in other water types such as freshwater, and inland-brackish water, the term salt content is used.

## 11.1 Pond-Based Aquaculture-Agriculture Systems

### 11.1.1 Introduction to Salt-Alkali Land

Salt-alkali soils are divided into saline soil and sodic soil. Saline-humid soil with high salt content but low pH is also introduced here. Influenced by seawater, the saline soil of coastal areas is mainly chlorinated. The inland saline soil and alkaline soil are mainly formed by the accumulation of salt and alkali in the surface soil after water evaporation. Saline-humid soil, rich in humic substances, is usually influenced by rhythmic ocean tides and has a low pH.

In China, there is about 34.67 million $hm^2$ of salt-alkali land, mainly distributed in the northeast, northwest, north China, and coastal areas. The salt-alkali land in northeast China is mainly saline soil and alkaline soil. The groundwater table is 1.5–3.0 m, and the salt content is 2–5 g/L. In some areas, salt content can even reach more than 10 g/L, and is dominanted by carbonate. Sulfates and chlorides dominate the salt-alkali soils in north China, and there are bicarbonate soils in partially closed, waterlogged areas. The groundwater table is 1.0–2.0 m and the salt content is 1–2 g/L. The salt content in the surface soil of salt-alkali land in northwest China is 1–10 g/kg, and the salt compositions are mainly sulfate and chloride. The groundwater table in the waterlogged areas is about 1.0 m, the salt content is 1–2 g/L, and the highest salt content can reach more than 10 g/L (Yang 2000). The saline soils in the coastal area are mainly chlorinated and mainly affected by seawater.

The formations of waterlogged salt-alkali land are mainly due to the low topography of the area, relatively high groundwater level, and long-time poor drainage of rainwater. Various soluble salts are redistributed horizontally and vertically in the topsoil, thus causing salts to gradually accumulate in the surface layer of the soil. The main means or techniques to exploit this part of the land is to directly or indirectly lower the water table and suppress the rate of water evaporation to reduce the salt content and alkalinity or acidity of the surface soil.

The salt-alkali land can be reclaimed by chemical, biological, and engineering measures. Phosphogypsum, furaldehyde residues, and peat have been used to reclaim alkaline soil and alkaline fluvo-aquic soils. In general, some chemical technical measures are not applied on a large scale due to the obvious side effects or immature of the technology (Song et al. 2000; Zhao et al. 2001).

China is a pioneer in the reclamation of salt-alkali land by using engineering technical measures (Li et al. 2003a). Methods including vertical drainage (or electromechanical drainage), open ditch drainage, concealed pipe drainage, and so on are commonly used to lower the groundwater table (Yang 2000). Electromechanical drainage can effectively reduce the groundwater table by pumping well water, but this method can only temporarily prevent the salt from rising to the surface. Once there is a major flood, or if the drainage stops then the previous

work will be in vain. The open ditch drainage and concealed pipe drainage methods can permanently solve the problem, but the project is large and costly.

The method of biodrainage, also known as afforestation, is also used to lower the groundwater table. Biological drainage is a method of reducing groundwater table in waterlogged areas through evapotranspiration of deep-rooted and fast-growing plants. The method uses biological energy rather than conventional electricity. According to the study of Singh and Lal (2018), the evapotranspiration of plants can reach 6500–28,000 $m^3/hm^2$, and the water table can decrease by 1–2 m in 3–5 years. The plants used are *Eucalyptus*, *Populus*, *Acacia,* etc. The biological drainage method can only be used in the area with the groundwater of low salt content and low alkalinity. In addition, the afforestation method has a very limited area to lower the water table, and the groundwater table a few hundred meters away from the afforestation area is barely affected (Yang 2000).

Some agricultural measures, such as deep plowing, application of organic fertilizer, and so on, can reduce soil alkalinity to some extent (Yang 2000). Nowadays, another engineering technology has been invented to reclaim waterlogged salt-alkali land and saline-humid land, that is, pond-based aquaculture-agriculture system, which will be illustrated in the following part. The system is capable of drainage and irrigation, which is a very efficient model of integrated development of aquaculture and agriculture in salt-alkali land (Dong 2003; Yang 2000).

### 11.1.2 Pond-Based Aquaculture-Agriculture Systems

In China, adjacent to the river system, there are three million $hm^2$ of deserted waterlogged salt-alkali land that can be exploited for aquaculture. In the 1990s, China began to use the digging ponds and raising land technology (Fig. 11.1) to construct the pond-based aquaculture-agriculture system (Dong 2003), which is also called land shaping technology in India (Dagar et al. 2019). The height of raising land should be at least 1 m higher than the critical depth above the groundwater table. In the areas with clay soil, the ponds are usually dug at a depth of 1.5–2 m in the original soil, and it is appropriate to build 1.5–2 m high terraces above the original ground. As for the sandy soil areas, it is suggested to dig 2–2.5 m deep to build the ponds and to raise land 2–2.5 m high for terraces. The pond-based aquaculture-agriculture systems are popular nowadays in China. The area ratio of

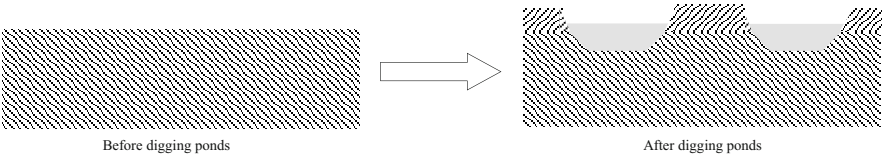


**Fig. 11.1** Longitudinal profile of waterlogged salt-alkali land before and after digging ponds

**Table 11.1** Salt contents in the soil of the terraces with different heights of bed (%) (from Duan et al. 2002)

| | Year 1997 | | | Year 1998 | | | Year 1999 | | |
|---|---|---|---|---|---|---|---|---|---|
| Sites | May | Jul. | Oct. | May | Jul. | Oct. | May | Jul. | Oct. |
| Control | 2.74 | 2.45 | 1.00 | 1.52 | 1.63 | 1.90 | 2.95 | 1.11 | 1.00 |
| Low terraces (1.35 m) | 1.35 | 0.69 | 0.32 | 0.56 | 0.30 | 0.75 | 0.99 | 0.86 | 0.59 |
| High terraces (2.63 m) | 0.39 | 0.56 | 0.17 | 0.23 | 0.087 | 0.27 | 0.26 | 0.63 | 0.077 |

ponds, terraces, and drainage ditches plus roads is 4:4:2 in Shandong Province, China.

After building the pond-based aquaculture-agriculture system, the salt-alkali water leaking into the pond from underground water is drained first, and then the freshwater from a river is introduced into the pond to culture fish.

As the soil of the excavated pond is used to build the terraces above the original ground, the groundwater table is relatively reduced, taking the terrace as a reference point, and the evaporation of groundwater is restrained. Over time, the salt content and alkalinity of the terrace soils will gradually decrease due to rainfall leaching and irrigation. For example, in Yucheng, Shandong Province, the terraces were raised by 2.63 m or 1.35 m, respectively, above the groundwater table. After 3 years of development, the salt contents of the terraces soil were significantly reduced (Table 11.1). However, the higher terraces are more effective in reducing the salt content in soil than the lower terraces. Meanwhile, the organic matter concentration in the soil of higher terraces increased from 0.58 to 0.99%, and the pH decreased from 8.35 to 7.91. The yield of wheat and maize planted on the terraces increased gradually over time (Duan et al. 2000, 2002).

It is even better when using the plastic film technology, i.e., putting a plastic film between the terrace and the original ground. The salt content of terraces (0.5 m high) with the film decreased from 23.54 g/kg to less than 12 g/kg after 2 years, while the salt content of the terraces (0.5 m high) without the film increased from 2.4 to 18 g/kg (Duan et al. 2000).

There was no apparent decrease of the salt content of the groundwater in this area after 3 years of aquaculture, but the salt content of the pond water had been maintained at a low level, which was suitable for culturing freshwater fish (Table 11.2).

In the waterlogged salt-alkali areas along the Yellow River in Shandong Province, many types of aquaculture-agriculture patterns such as fish-cereal crop, fish-cotton, fish-alfalfa, fish-duck, fish-fruit plants, fish-mulberry, etc., have been developed recently. The development of the patterns is determined by the geographical characteristics, resources, soil conditions, and the groundwater table of the area (Gu et al. 2000).

**Table 11.2** Salt contents (g/L) in ponds and underground water after digging pond and raising land (from Duan et al. 2002)

| Time | | Year 1997 | | | Year 1998 | | | Year 1999 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | May | Jul. | Oct. | May | Jul. | Oct. | May | Jul. | Oct. |
| Yuxi | Pond water | 2.27 | 1.54 | 3.41 | 1.41 | 1.85 | 1.59 | 1.79 | 1.72 | 1.78 |
| | Underground water | 6.12 | 7.21 | 4.69 | 4.96 | 7.05 | 6.42 | 5.07 | 5.42 | 6.03 |
| Gaoqing | Pond water | 1.62 | 1.69 | 1.59 | 1.23 | 1.69 | 1.53 | 1.25 | 1.34 | 1.50 |
| | Underground water | 10.00 | 13.43 | 10.01 | 15.55 | 14.42 | 12.79 | 13.28 | 10.85 | 11.41 |

In the Pearl River Delta region of China, the integration of aquaculture and agriculture has also been developed by using ditch-terrace systems. The fruits, vegetables, etc., are planted on raised terraces, while fish, snails, or aquatic plants are cultured in the ditches (Yang 2000). In sum, the technique can be used in various types of waterlogged land.

The waterlogged acidic saline-humid soils affected by marine tides can also be developed using the above-mentioned method. In India, Velmurugan et al. (2016) built the raised bed and furrow (RBF) system in the coastal lowlands of the humid tropics to reduce the soil salt content in the area. The annual rainfall in that area is 2900–3100 mm, the salt content of the surface-clayed soil is 7.19 ± 1.34 g/L, and the pH and the organic carbon content of the soil are 4.9 ± 1.1 and 8.7 ± 1.83 g/kg, respectively. The furrows of 1.5 m deep and 6 m wide were dug. The 1 m high beds were made by excavating the soil from either side of the bed and putting it in the bed area. The bed soil was washed by rainfall to reduce salt, and the natural rainwater was collected in the furrows. The water depth of furrows was 20–60 cm in dry seasons and 100–120 cm in rainy seasons. The salt content of the bed soil decreased from 6.98 g/L in March 2009 to 0.96 g/L in March 2013, and the salt content of the furrow water also decreased from 1.66 to 0.45 g/L, which could be used to culture freshwater fish.

## 11.2 Water Quality and Biological Environment of Salt-Alkali Ponds

### 11.2.1 Water Quality of Salt-Alkali Ponds

The ratio of the ions is usually not balanced in salt-alkali ponds. The ion compositions of water vary in different areas. The general trend is when evaporation is getting strong and there is less precipitation, the process named land salinization is accelerated. Accompanied by the increase in salt content, the $Na^+$ will gradually replace $Ca^{2+}$ and $Mg^{2+}$ in the water. For the anions, the $SO_4^{2-}$ and $Cl^-$ will gradually replace $HCO_3^-$. At the same time, other physical and chemical parameters and biological compositions of the pond water also change.

The middle reaches, lower reaches, and estuaries of the Yellow River have a large area of typical waterlogged salt-alkali land, where large-scale pond-based aquaculture-agriculture systems are concentrated. In the upper reaches of the Yellow River, the temperature and evaporation are low, the soil is dominated by mountain meadow soil. The salt contents in soil and water are generally low, and the water usually belongs to the bicarbonate type. The middle reaches of the Yellow River are in arid and semi-arid regions. The soil and groundwater in the area have high salt and alkali contents, and most of the water belongs to the carbonate type. The groundwater in some regions (such as Gan-ning Bitter Water Area) and some water bodies (such as Lake Qianjinhu in the Ningxia Hui Autonomous Region) belong to the sulfate water type (The Fishery Resources Survey Collaborating Group of the

Yellow River 1986). The salt content in the soil and groundwater of the lower reaches of the Yellow River is usually not high, but there is still some waterlogged salt-alkali land along the two sides of the Yellow River. The salt content and ion compositions of the soil and groundwater in the Yellow River estuary are mainly influenced by seawater, the main cation is $Na^+$ and the anion is $Cl^-$.

Along the Yellow River in Shandong Province, from coastal heavy salt-alkali land up to inland waterlogged salt-alkali land, the proportion of chloride ions in water gradually decreases, but the proportion of carbonate and bicarbonate increases gradually. In general, the salt contents of groundwater in these waterlogged salt-alkali lands are less than 5 g/L, but the alkalinity and pH of pond water are high. The pH of pond water is generally above 8.0, and in some cases can exceed 9.0. Although the alkalinity of soil and pond water decreases in July due to rainfall, it is also generally above 2.0 mmol/L and tends to increase with distance from the estuary.

There are obvious seasonal variations in water quality in salt-alkali ponds (Zhang et al. 2000). For example, conductivity varied in the range of $1.46 \times 10^3$– $9.75 \times 10^3$ μs/cm of the pond water in Gaoqing, Shandong province. The lowest values occurred in ponds that had just been filled with Yellow River water, and the highest values occurred in ponds that had gone out of use for several years. Alkalinity, which was mainly composed of the bicarbonate alkalinity, ranged from 1.73 to 11.6 6 mmol/L with the average value of 5.98 mmol/L. Alkalinity was lower in July and August, and higher in winter. The pH varied from 7.08 to 9.64 throughout the year, with an average value of 8.29. The lowest values were observed in October and November. Daily fluctuations of pH were also obvious in the ponds because of the poor buffering capacity of the water. The buffering process could be illustrated by the following two equations, which exist in the water of salt-alkali ponds:

$$2HCO_3^- \leftrightarrow CO_3^{2-} + CO_2 + H_2O$$

$$CO_3^{2-} + Ca^{2+} \leftrightarrow CaCO_3 \downarrow$$

The photosynthesis process consumes $CO_2$, and more $CO_3^{2-}$ will be produced. When there is abundant $Ca^{2+}$ in water, it could react with $CO_3^{2-}$ to form $CaCO_3$ precipitate, slowing the rise of pH in the water. When photosynthesis weakens, the respiration process will produce more $CO_2$ to promote the dissolution of $CaCO_3$. The $CO_2$ homeostasis system and the presence of $Ca^{2+}$ ions will act as an effective buffer against pH changes in the water. However, $Ca^{2+}$ is often deficient in salt-alkali ponds, and thus the buffering capacity of the water is greatly reduced, which may endanger the safety of farmed animals in the ponds (Wen et al. 2000).

In general, P is the limiting nutrient element in freshwater ponds, while N is the limiting nutrient element in seawater ponds. N is usually the limiting nutrient element in chloride type of salt-alkali ponds (Wen et al. 1999), which is probably due to the high ionic strength and high solubility of the phosphate compounds in salty water.

## 11.2.2 Aquatic Organisms of Salt-Alkali Ponds

### 11.2.2.1 Phytoplankton and Primary Productivity in Salt-Alkali Ponds

In general, the higher the salt content, alkalinity, and pH, the lower the quantity of phytoplankton species and diversity index (Zhao 1992; He et al. 1989). In the late 1990s, a total of 120 genera and 197 species of phytoplankton were detected in a chloride type of waterlogged salt-alkali pond in Gaoqing, Shandong Province. There were 76 species and 45 genera in Chlorophyta, which accounted for 38.58% of the whole phytoplankton community. There were 46 species and 28 genera in Bacillariophyta, which was the second most abundant phylum, and accounted for 23.35% of the community. The phytoplankton was mostly salt tolerant or halophile species, and some of them were typical saltwater species (Zhao et al. 2002; Shentu et al. 2000a).

There are apparent seasonal variations of phytoplankton biomass in ponds. The phytoplankton biomass in the salt-alkali ponds in Gaoqing ranged from 0.60 to 368 mg/L with an average of 49.90 ± 31.92 mg/L. Phytoplankton less than 10 μm in diameter contributed more to the biomass and primary production in the ponds (Zhao and Dong 2003).

The average chlorophyll *a* content in waterlogged salt-alkali ponds in Gaoqing was 115.12 μg/L, and chlorophyll *a* accounted for 61.76% of the total chlorophyll content. The chlorophyll *a* content was positively correlated to phytoplankton biomass, water temperature, total nitrogen, total phosphorus, and silicate content, and negatively correlated to the transparency of pond water (Zhao et al. 2000c).

In the farming season (from April to September) of the salt-alkali ponds in Gaoqing, the primary productivity of phytoplankton was 9.42 ± 4.21 $gO_2/(m^2 \cdot d)$, the daily *P/B* coefficient was 0.24 ± 0.18, and the utilization rate of effective solar radiation by phytoplankton was 1.53%. The main ecological factors affecting the primary productivity of phytoplankton in salt-alkali ponds were phytoplankton biomass, transparency, water temperature, and salt content (Zhao et al. 2003).

### 11.2.2.2 Zooplankton in Salt-Alkali Ponds

A total of 89 genera and 159 species of zooplankton were detected in the salt-alkali ponds in Gaoqing. The most numerous zooplankton were protozoans, with 48 genera and 78 species. The second ones were rotifers, with 27 genera and 58 species. Zooplankton were mainly halophile or salt-tolerant species, some of which were typical saltwater species (Zhao et al. 2001a). The biomass of zooplankton varied from 0.002 to 308 mg/L with the average of 9.47 mg/L. Two peaks of zooplankton biomass were observed in spring and early autumn.

### 11.2.2.3 Macrophytes and Benthic Animals in Salt-Alkali Ponds

A total of 12 species of macrophytes were found in the salt-alkali ponds in Gaoqing, characterized by few species but prominent dominant species (Zhao et al. 2001b). Under the conditions of water surface illumination of 7200 Lx and water temperature of 28–30 °C, the gross primary productivity of the dominant species *Potamogeton crispus*, *Zannichellia palustris,* and *Charophyllum* sp. are 1.70, 1.56, and

1.50 $mgO_2/(h \cdot g)$, respectively. The primary productivity of these macrophytes is significantly affected by light intensity, temperature, pH, salt content, and alkalinity of the water. For example, *P. crispus* and *Z. palustris* have the highest primary productivity at a salt content of 3 g/L. The highest primary productivities occur at the water alkalinity of 6.69 and 3.82 mmol/L for the two species, respectively.

A total of 14 species (3 phyla and 6 classes) of zoobenthos were found in salt-alkali ponds in Gaoqing. There were 3 species and 3 families in Gastropod class of Mollusca; 4 species and 3 classes in Annelida phylum; 7 species, 4 orders, and 2 classes in Arthropoda phylum. The dominant species were *Chironomus plumosus* and *Limnodrilus udekemianus* (Zhao et al. 2001c). The density and biomass of zoobenthos in the ponds without farmed fish were much higher than those with farmed fish. For example, the density and biomass of zoobenthos in the ponds without fish were 40–2085 ind./$m^2$ and 0.15–12.9 g/$m^2$, respectively, while those with fish were 54–161 ind./$m^2$ and 0.14–0.54 g/$m^2$, respectively. There was a peak in the density and biomass of zoobenthos at the turn of spring and summer.

## 11.3 Salt and Alkalinity Tolerance of Aquaculture Animals

The pH, salt content, and alkalinity of water have a significant impact on the farmed animals in the waterlogged saline-alkali ponds. These three factors are also the more commonly used water quality indicators for water quality regulation in ponds, so it is of great theoretical and practical importance to understand the effects of these factors on farmed animals.

### 11.3.1 Effects of pH on Aquacultured Animals

The buffering capacity for acids and bases of water in salt-alkali ponds is usually poor due to a deficiency in $Ca^{2+}$ concentration. Dramatically rising pH to a certain threshold due to intensive photosynthesis may stress aquatic animals, especially the young fry. There is an interaction effect between pH and $Ca^{2+}$ on the growth and energy budget of shrimp (*Macrobrachium nipponense*) by affecting the energy ingestion of the animals (Dong et al. 1994).

The tolerance range of pH for black carp (*Mylopharyngodon piceus*), grass carp, silver carp, and bighead carp are 4.6–10.2, while the range for common carp is 4.4–10.4. The carp can sense small changes in pH of 0.2 (Zhang 1960). In terms of alkaline tolerance, black carp and grass carp can tolerance higher alkalinity than silver carp and bighead carp; while in terms of acid tolerance, black carp, grass carp, and bighead carp are stronger than silver carp. The concentration of hydrogen ions in water could affect the respiration physiology of fish. When the concentration of hydrogen ions is not in the appropriate range, fish requires more dissolved oxygen for respiration. The juvenile common carp could obtain less oxygen at pH 4.0 than at pH 7.0. In the temperature range of 18–26 °C, when the pH is 4.0, the low pH can damage the respiratory system of juvenile common carp. If the obtained dissolved oxygen by the fish is less than 7.0 mg/L, the mortality rate of the fish is very high.

### 11.3.2 Salt Tolerance of Aquiculture Animals

The tolerance of fish, shrimp, and crab to salt content has been studied by diluting seawater, adding NaCl to tap water, adding NaCl to salt-alkali water, or evaporating salt-alkali water. Eight species of aquatic animals are commonly cultured in water-logged salt-alkali ponds in Shandong Province, China. NaCl contents of $LC_{50}$ for these species in the pH range of 8.2–8.9 are listed in Table 11.3. The $LC_{50}$ of these species is in the order of mitten carb ≈ giant freshwater prawn < red pacu ≈ gibel carp ≈ crucian carp ≈ silver carp < common carp < Nile tilapia (Zhang et al. 1999c; Zheng et al. 2001; Wang et al. 2001a).

Zang et al. (1989) also studied the salt tolerance of farmed fish under pH 7.00–9.90, and the salt tolerance order of fish studied is bighead carp > grass carp > blunt snout bream (*Megalobrama amblycephala*) > silver carp. The optimal salt content for giant freshwater prawns is 0–6.83, and the survival of the species is not affected when the salt content is less than 15.66 (Zheng 1993).

Likongwe et al. (1996) studied the effects of temperature (24, 28, and 32 °C) and salt content (0, 8, 12, and 16 ppt) on the growth and feed utilization efficiency of juvenile Nile tilapia. Results showed that temperature, salt content, and their interactions had significant effects on feed conversion and protein utilization efficiency of the fish. The growth rate and feed utilization rate were the highest at 32 °C and salt content of 8 ppt, and lowest at 28 °C and salt content of 16 ppt.

Allan and Maguire (1992) studied the effects of pH and salt content on the survival, growth, and osmotic pressure of shrimp (*Penaeus monodon*), and found that the 96 h $LC_{50}$ of pH for the shrimp was 3.7 when salinity was 32 ppt. But the value was 5.9 when salinity was 30 ppt. The interactions between salinity and pH were significant.

**Table 11.3** NaCl contents (g/L) of $LC_{50}$ for different aquaculture species (data from Zhang et al. 1999c; Zheng et al. 2001; Wang et al. 2001a)

| Species | 24 h | 48 h | 72 h | 96 h | pH and water temperature (°C) |
|---|---|---|---|---|---|
| Red pacu (*Colossoma brachypomum*) | 11.99 | 11.41 | 10.99 | 10.43 | 8.21 ± 0.07, 23 ± 1.0 |
| Nile tilapia (*Tilapia nilotica*) | 18.37 | 14.66 | 14.39 | 14.25 | 8.91 ± 0.11, 18–23 |
| Common carp (*Cyprinus carpio*) | 13.69 | 13.46 | 12.01 | 11.91 | 8.60 ± 0.18, 25 ± 2.0 |
| Silver carp (*Hypophthalmichthys molitrix*) | 11.24 | 8.96 | 8.55 | 8.15 | 8.60 ± 0.18, 23 ± 2.0 |
| Gibel carp (*Carassius auratus gibelio*) | 11.53 | 10.77 | 9.35 | 8.58 | 8.8 ± 0.1, 24.5 ± 1.5 |
| Crucian carp (*Carassius auratus*) | 10.23 | 7.91 | 7.81 | 7.78 | 8.56 ± 0.25, 25 ± 1.0 |
| Mitten carb (*Eriocheir sinensis*) | 8.12 | 6.47 | 5.29 | 4.88 | 8.33 ± 0.13, 20.3 ± 1.4 |
| Giant freshwater prawn (*Macrobrachium rosenbergii*) | 8.58 | 5.32 | 3.47 | 2.19 | 8.40 ± 0.18, 23.6 ± 1.0 |

### 11.3.3 Alkalinity Tolerance of Aquaculture Animals

The $LC_{50}$ of several fish species to alkalinity was tested by using the concentrated water from Dali Lake, Inner Mongolia Autonomous Region (Shi 1981). Dali lake is a salt-alkali lake with a pH of about 9.4, total alkalinity of 44.5 mmol/L, and salt content of 5.5 ppt. The results showed that the order of tolerance to the alkalinity of tested fish was: naked carp (*Gymnocypris przewalskii*) > amur ide (*Leuciscus waleckii*) ≈ topmouth gudgeon (*Pseudorasbora parva*) > crucian carp. The chronic toxic effects of high alkalinity and high pH saline water on fish have common characteristics, i.e., rotten fins, blindness, muscle ulcers, and gangrene, which is also known as 'alkalosis' or fibrous corrosion and necrosis.

The main composition of alkalinity that is toxic to farmed fish is $CO_3^{2-}$, and the 24 h $LC_{50}$ value of $CO_3^{2-}$ for silver carp is 12.4 meq/L (Lei et al. 1985). Water pH could change the proportion of $CO_3^{2-}$ in total $CO_2$ homeostasis system and causes synergistic effects with alkalinity on fish. The safety threshold of alkalinity for fish farming is 10 meq/L. The order of alkalinity tolerance of commonly cultured species in waterlogged salt-alkali ponds is Nile tilapia > spotted sea bass ≈ crucian carp ≈ gibel carp > giant freshwater shrimp ≈ mitten crab ≈ red pacu > silver carp (Table 11.4).

**Table 11.4** $LC_{50}$ (mmol/L) of alkaline for different species (data from Zhang et al. 1999c; Zheng et al. 2001; Wang et al. 2001a)

| Species | 24 h | 48 h | 72 h | 96 h | pH and water temperature (°C) |
|---|---|---|---|---|---|
| Red pacu (*Colossoma brachypomum*) | 83.25 | 56.99 | 53.43 | 45.70 | 8.85 ± 0.18, 23 ± 1.0 |
| Nile tilapia (*Tilapia nilotica*) | 142.1 | 128.28 | 124.25 | 103.62 | 8.32 ± 0.35, 18–21 |
| Common carp (*Cyprinus carpio*) | 55.91 | 25.94 | 23.41 | 21.33 | 8.59 ± 0.33, 25 ± 2.0 |
| Silver carp (*Hypophthalmichthys molitrix*) | 51.41 | 27.06 | 23.74 | 15.74 | 8.74 ± 0.34, 23 ± 2.0 |
| Gibel carp (*Carassius auratus gibelio*) | 98.74 | 79.49 | 74.08 | 64.19 | 8.84 ± 0.26, 24.5 ± 2.5 |
| Crucian carp (*Carassius auratus*) | 90.29 | 69.15 | 60.82 | 59.82 | 8.87 ± 0.29, 25 ± 1.0 |
| Spotted sea bass (*Lateolabrax maculatus*) | 101.05 | 63.27 | 56.84 | 46.18 | 8.4 ± 0.25, 18.5 ± 0.5 |
| Mitten carb (*Eriocheir sinensis*) | 52.97 | 42.44 | 26.27 | 24.96 | 8.33 ± 0.17, 20.3 ± 1.4 |
| Giant freshwater prawn (*Macrobrachium rosenbergii*) | 51.02 | 37.02 | 27.19 | 21.54 | 8.59 ± 0.31, 23.6 ± 1.0 |

Some experiments have proved that the toxic effects of NaCl content and alkalinity on farmed aquatic animals are synergistic. The relationship equations of NaCl content (S) and alkalinity (Alk) in 24 h $LC_{50}$ value are:

| | |
|---|---|
| Red pacu | Alk = 256.2–24.69 S, $n = 8$, $r^2 = -0.9017$; |
| Nile tilapia | Alk = 513.9–29.79 S, $n = 5$, $r^2 = -0.9878$; |
| Common carp | Alk = 78.89–4.777 S, $n = 5$, $r^2 = 0.9195$; |
| Silver carp | Alk = 34.17–1.78 S, $n = 6$, $r^2 = 0.7247$; |
| Giant freshwater shrimp | Alk =72.15–7.813 S, $n = 7$, $r^2 = -0.9920$; |
| Spotted sea bass | Alk =125.1–2.18 S, $n = 7$, $r^2 = 0.9518$; |

The suitable alkalinity for the growth of Nile tilapia is <8 mmol/L; the suitable NaCl content for the growth of mitten crab is <1.0 g/L; and the suitable alkalinity and NaCl content for the growth of red pacu are <5 mmol/L and <7.0 g/L, respectively.

## 11.4 Effects of Cations in Water on Shrimp

Whiteleg shrimp (*L. vannamei*) is a disease-resistant, euryhalinity, and fast-growing economic crustacean, and has been widely farmed in inland and coastal salt-alkali ponds in many countries. However, due to the great difference in water quality in different regions, especially the difference in concentration and composition of cations, mass mortality of farmed whiteleg shrimp is common at the juvenile stage. The main cations in water include $K^+$, $Na^+$, $Ca^{2+}$, and $Mg^{2+}$. Both absolute quantities and the proportions of the cations could significantly affect the growth and development of shrimp. Therefore, this section will focus on the effects of cations in water on the growth of the whiteleg shrimp.

### 11.4.1 Adaptability of Shrimp to $Na^+/K^+$ Ratios in Water

$K^+$ content of groundwater in many salt-alkali areas is low and cannot be used directly for shrimp culture or the culture results are not satisfactory. The specific growth rates of whiteleg shrimp in the water with $Na^+/K^+$ ratios ranging from 47 to 76 are significantly higher than that with $Na^+/K^+$ ratios over 98 (Zhu et al. 2005). The $Na^+/K^+$ ratios of the water have significant effects on the energy budget of the shrimp (Table 11.5). The $Na^+/K^+$ ratios of water can affect the growth of the shrimp by influencing the food conversion efficiency and the proportion of energy allocation to growth. When the shrimp is cultured in $K^+$-deficient water with a salt content of around 15 ppt, it is necessary to reduce the $Na^+/K^+$ value of water to below 76 by adding potassium salt into the water to obtain better farming results.

When the salt content of the water increases to 30 ppt, the effect of $Na^+/K^+$ ratios on the growth of the shrimp becomes inconspicuous (Fig. 11.2). Salt content, $Na^+$/

**Table 11.5** Effects of $Na^+/K^+$ ratios on the energy budget of *L. vannamei* at salinity 15 ppt (from Zhu et al. 2004)

| $Na^+/K^+$ | *C* (kJ) | *G*/*C* (%) | *R*/*C* (%) | *F*/*C* (%) | *U*/*C* (%) | *E*/*C* (%) |
|---|---|---|---|---|---|---|
| 47 | $48.22 \pm 2.35^{a}$ | $18.30 \pm 1.02^{a}$ | $62.67 \pm 1.06$ | $12.78 \pm 0.39^{a}$ | $5.45 \pm 0.16$ | $0.80 \pm 0.15^{a}$ |
| 62 | $46.80 \pm 5.62^{ab}$ | $18.14 \pm 0.33^{a}$ | $62.31 \pm 0.35$ | $12.87 \pm 0.69^{a}$ | $5.52 \pm 0.01$ | $1.16 \pm 0.08^{ab}$ |
| 76 | $45.11 \pm 2.09^{abc}$ | $18.86 \pm 1.11^{a}$ | $61.59 \pm 1.32$ | $12.74 \pm 0.42^{a}$ | $5.83 \pm 0.13$ | $0.98 \pm 0.15^{a}$ |
| 88 | $38.46 \pm 1.71^{bc}$ | $18.30 \pm 1.50^{a}$ | $60.06 \pm 1.96$ | $14.74 \pm 1.15^{ab}$ | $5.51 \pm 0.23$ | $1.38 \pm 0.12^{ab}$ |
| 98 | $36.26 \pm 2.53^{c}$ | $13.48 \pm 1.42^{b}$ | $65.77 \pm 2.00$ | $13.07 \pm 0.80^{a}$ | $5.88 \pm 0.30$ | $1.80 \pm 0.11^{bc}$ |
| 116 | $36.85 \pm 1.19^{c}$ | $13.55 \pm 1.50^{b}$ | $62.61 \pm 1.49$ | $16.12 \pm 0.37^{b}$ | $5.73 \pm 0.25$ | $1.99 \pm 0.27^{c}$ |

Note: $Na^+ + K^+$ is 239 mmol. The values with different letters in the same column are significantly different from each other ($P < 0.05$)

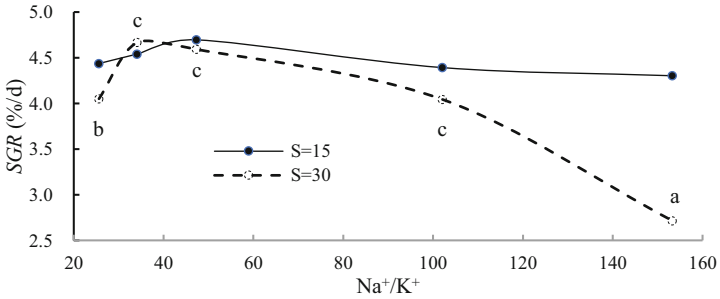


**Fig. 11.2** Specific growth rate of whiteleg shrimp reared at different salinities and $Na^+/K^+$ ratios (from Zhu et al. 2006a). Means with different letters within the same salt content are significantly different ($P < 0.05$)

$K^+$ ratio and their interactions could significantly affect the growth of the shrimp (Zhu et al. 2004, 2006a).

The shrimp may not be able to absorb K element effectively from feed, and only the $K^+$ concentration in water has a significant effect on the growth of shrimp (Zhu et al. 2006b).

In the Yellow River Delta of China, southern Australia, and some coastal regions of India, the groundwater is chloride type and the salt composition of the water is mostly identical to seawater. However, the $K^+$ concentration is usually 90–95% lower than that of normal seawater, and the $Na^+/K^+$ ratio is 8–20 times higher than those of normal seawater. Therefore, special attention should be paid to potassium deficiency when culturing shrimp or fish in these or similar areas.

### 11.4.2 Adaptability of Shrimp to $Ca^{2+}$ Concentration in Water

Calcium in water plays an important role in the survival, growth, and metabolism of crustaceans. A moderate increase in $Ca^{2+}$ concentration under low salt content conditions can significantly improve the survival of shrimp. At the salt content of 0.5 ppt, $Ca^{2+}$ concentration below 15 mg/L will significantly affect the growth of whiteleg shrimp. The adaptability of shrimp to $Ca^{2+}$ is salt content dependent, and more $Ca^{2+}$ is required with higher salt content. At a $Ca^{2+}$ concentration of 5 mg/L, the survival rates of the shrimp are about 80%, 70%, and 0% at salt contents of 0.5, 5, and 10 ppt, respectively (Hou 2011). At the salt content of 15 ppt and $Ca^{2+}$ concentrations of 180–750 mg/L, the shrimp grow fastest and the proportion of ingested energy allocated to growth is the largest (Dong et al. 2005).

The adaptability of Chinese shrimp (*F. chinensis*) to $Ca^{2+}$ is also salt content dependent, and the shrimp requires more $Ca^{2+}$ at higher salt content. At the salt content of 5 ppt, the 96-h survival rates of juvenile Chinese shrimp are 46.7 and 93.3% at $Ca^{2+}$ concentrations of 0.0 mg/L and 43.75 mg/L, respectively. At the salt

content of 15 ppt, the 96-h survival rates are 0 and 3.3% at $Ca^{2+}$ concentrations of 0.0 mg/L and 43.75 mg/L, respectively.

$Ca^{2+}$ concentration affects the growth energy accumulation of Chinese shrimp by affecting its feeding and metabolic rate. When the $Ca^{2+}$ concentration is 1200 mg/L, the energy allocated to growth can reach 24.5%. In shrimp culture, increasing $Ca^{2+}$ concentration in calcium-deficient water can significantly improve aquaculture efficiency (Dong 2005).

### 11.4.3 Adaptability of Shrimp to $Mg^{2+}/Ca^{2+}$ Ratios in Water

At the salt content of 30 and the $Mg^{2+}/Ca^{2+}$ ratio in the range of 0.11–7.87, the survival rate of juvenile whiteleg shrimp is 100%. However, there is high mortality at the $Mg^{2+}/Ca^{2+}$ ratio of 11.81 and the $Ca^{2+}$ concentration of 94 mg/L, which is mostly due to the difficulty of hardening the shell after molting (Zhu et al. 2010). Just as mentioned above, juvenile whiteleg shrimp grow well at the salt content of 15 ppt and the $Ca^{2+}$ concentration of 60 mg/L. Thus, the mortality of the shrimp may be related to the improper $Mg^{2+}/Ca^{2+}$ ratios instead of the $Ca^{2+}$ concentrations in water.

When the $Mg^{2+}/Ca^{2+}$ ratio is in the range of 0.53–7.87, the energy intake and the energy allocated to the growth of whiteleg shrimp are relatively great, and respiration and excretion are normal. In production, it is recommended to keep the $Mg^{2+}/Ca^{2+}$ ratio in the range of 0.5–5.0 to obtain better growth of the shrimp.

Zhu (2005) has also studied the effect of water $(Mg^{2+} + Ca^{2+})/(Na^{+} + K^{+})$ ratios on the growth and budget of whiteleg shrimp. Among the seven ratios ranging from 0.05 to 0.71, the shrimp have a significantly less growth energy allocation at the ratio of 0.05 than the other six ratios, however, there are no differences in growth among the seven ratios. Whiteleg shrimp is weaker to tolerate lower $(Mg^{2+} + Ca^{2+})/(Na^{+} + K^{+})$ ratios in water and somewhat stronger to tolerate higher $(Mg^{2+} + Ca^{2+})/(Na^{+} + K^{+})$ ratios.

## 11.5 Water Quality Management in Salt-Alkali Ponds

For ponds with high levels of sulfur iron ($FeS_2$), common in coastal brackish water areas, the application of lime is enough to improve their water quality (see Chap. 8 for details). In contrast, water quality management in salt-alkali ponds is complex, and many physical, chemical and biological methods have been developed to improve their water quality. The pond-based aquaculture-agriculture-terrace system described above is one type of physical method; moreover, aeration and sediment stirring can be conducted in the pond to improve the water quality. Chemical and biological methods will be introduced in the following part.

### 11.5.1 Effects of Fertilization on Water Quality of Salt-Alkali Ponds

Both inorganic fertilizer and organic fertilizer are used. Inorganic fertilizer refers to the chemical compounds containing large amounts of elements such as nitrogen, phosphorus, and potassium, while organic fertilizer mainly refers to manure. The feed residuals and feces can also be regarded as organic fertilizer.

As the water alkalinity and pH of the ponds in salt-alkali land are high, the use of alkaline fertilizers is undoubtedly inappropriate. Acidic fertilizers should be used, which not only provide the necessary nutrients for the pond but also neutralize alkalinity, reducing the threat of high alkalinity and pH to farmed fish and shrimp.

Acidic fertilizers, such as urea (carbamide) and ammonium nitrogen fertilizer, are often applied in the pond (Boyd 1982):

$$(NH_2)_2CO + H_2O \rightarrow 2NH_3 + CO_2$$

$$2NH_3 + 2H_2O \rightarrow 2NH_4^+ + 2OH^-$$

$$2NH_4^+ + 4O_2 \rightarrow 4H^+ + 2NO_3^- + 2H_2O$$

According to the above equations, nitrification of 1 mmol urea or ammonium nitrogen can produce 2 mmol acid and reduce 2 mmol alkalinity. However, as ammonium nitrogen is the primary nitrogen source of phytoplankton, the ammonium nitrogen applied is usually absorbed by phytoplankton before nitrification when there is light in the pond. In this way, the alkalinity in the pond will not decrease but increase. An increase in alkalinity and pH were reported in previous studies after ammonium nitrogen application (Pote 1990; Knud-Hansen and Pautong 1993). Similarly, the application of nitrate fertilizer will also increase alkalinity and pH due to photosynthesis. The process is illustrated in the following equation:

$$106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+ \rightarrow C_{106}H_{263}O_{110}N_{16}P + 138O_2$$

Thus, the application of urea and inorganic fertilizer to the salt-alkali pond that is low in inorganic nitrogen generally increases alkalinity and pH. The experiment of Shentu (1999) also showed that different levels of pH increase were observed after applying $NH_4Cl$, $NH_4NO_3$, and $(NH_4)_2SO_4$ in ponds. Hence, attention should be paid when these inorganic fertilizers are used to prevent the alkalinity and pH from rising too high to harm the cultured animals.

In addition to nitrogen and phosphorus, organic fertilizer also contains trace elements such as iron, manganese, zinc, and copper. The organic matter in the organic fertilizer can be mineralized under the action of bacteria.

$$C_{106}H_{263}O_{110}N_{16}P + 138O_2 \rightarrow 106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+$$

The mineralization process can not only provide nutrients for the ponds but also produce carbon dioxide and organic acids that can reduce the pH of the pond water. Previous studies reported the reduction of alkalinity after the application of organic fertilizers (Manjunatha and Shetty 1991). The decrease in total alkalinity is the result of organic acid production, while the $CO_2$ generated by decomposition can lower the pH of the water. Assuming the organic matter contains 35.8% carbon, in theory, 1.31 kg $CO_2$ can be produced when 1 kg of organic matter is completely decomposed. These $CO_2$ can produce 29.8 mol acidity, which can dissolve 2.98 kg of $CaCO_3$, i.e., producing 2.98 kg alkalinity (calculated by $CaCO_3$) (Boyd 1997). Therefore, the application of organic fertilizer could significantly reduce the pH in salt-alkali ponds, which is proven by many researchers (Yang 2000).

But organic fertilizer also has many disadvantages. Organic fertilizer has a slow effect and unstable nitrogen content. Moreover, compared with the amount of phosphorus, the nitrogen content of organic fertilizer is usually low. Therefore, organic and inorganic fertilizers are often used together in salt-alkali ponds to stimulate microbial activity and promote the decomposition of organic fertilizer.

Residual feeds have similar effects on water quality as organic fertilizer. Hence, the uneaten feed and feces can increase the carbon dioxide in a pond and decrease the water pH (Zhang et al. 2002a).

## 11.5.2 Water Quality Improvers for Salt-Alkali Ponds

The $K^+$ deficiency and high pH in salt-alkali pond water often harm the farmed animals. Application of KCl and $CaCl_2$ can effectively improve the water quality of the pond, and increase the survival rate and yield of cultured animals.

### 11.5.2.1 Effects of KCl Application on Shrimp Farming

Shrimp farming in salt-alkali ponds is popular in China, giving a strong impetus to the exploitation of salt-alkali lands. However, $K^+$ deficiency is found in the soil and groundwater of many salt-alkali areas due to the chemical geological processes over a long period of time. When using the water for aquaculture, the $K^+$ deficiency or unbalanced cations may harm cultured animals, causing unnecessary losses from time to time. The $K^+$ deficiency was also reported in Australian snapper (*Pagrus auratus*) culture in Australia and shrimp culture in India. We have tried to solve this problem by adding KCl to the shrimp feed, but it didn't work well. The effects of KCl application to the $K^+$ deficiency ponds in Dongying, Shandong Province, are shown in Table 11.6. The original $Na^+/K^+$ (mol/mol) ratio of the pond water was 154, in which whiteleg shrimp would die in days after stocking. By applying different amounts of KCl to the ponds the $Na^+/K^+$ (mol/mol) ratios were decreased. The highest survival rate, yield, and food conversion rate were achieved at the $Na^+/K^+$ of 40 (Table 11.6).

**Table 11.6** Net production, body weight, and survival of *L. vannamei* in the brackish water ponds at different $Na^+/K^+$ ratios (from Jie 2006)

| $Na^+/K^+$ (mol/mol) | Yields (g/45 $m^3$) | Weight (g/ind.) | Survival (%) |
|---|---|---|---|
| 10 | $2840.5 \pm 24.6^a$ | $12.17 \pm 1.48^a$ | $23.55 \pm 2.53^a$ |
| 20 | $6969.3 \pm 539.9^b$ | $11.53 \pm 3.13^a$ | $63.23 \pm 15.55^b$ |
| 40 | $8323.1 \pm 343.6^c$ | $11.92 \pm 2.53^a$ | $71.86 \pm 14.52^b$ |
| 80 | $7966.3 \pm 45.9^c$ | $11.78 \pm 1.95^a$ | $68.87 \pm 11.11^b$ |
| 154 (control) | 0 | 0 | 0 |

Note: Salt content of the pond water was 9 ppt

#### 11.5.2.2 Effects of $CaCl_2$ Application on Water Quality in Pond

A certain concentration of $Ca^{2+}$ is required by shrimp. In addition, the buffering capacity of water is poor when there is a lack of $Ca^{2+}$ in water, which is common in chloride-type salt-alkali ponds. The poor buffering capacity will lead to drastic fluctuations in pH when there is strong photosynthesis by phytoplankton, which is harmful to cultured animals. Therefore, Shentu et al. (2000b) applied $CaCl_2$ to the pond to reduce the alkalinity and pH of pond water and demonstrated that $CaCl_2$ was an efficient improver on the water quality in salt-alkali ponds.

As can be seen from Fig. 11.3, after the application of 2 mmol/L $CaCl_2$ for 2 days, the pH of pond water decreased significantly. Although the pH increased slowly then, it remained at a relatively low level after 16 days. The total alkalinity decreased dramatically in the first 2 days and then decreased slowly in the following 14 days. Thus, $CaCl_2$ fertilization can effectively reduce the pH and total alkalinity, and improve the buffering capacity of water. In addition, $CaCl_2$ fertilization can significantly increase the phytoplankton diversity without a change in the phytoplankton biomass.

#### 11.5.2.3 Effects of Other Acidic Chemicals Application on Water Quality in Pond

Boyd and Tucker (1998) suggested introducing carbon dioxide or strong acids to reduce the pH of pond water. Hydrochloric acid can quickly reduce the water pH for

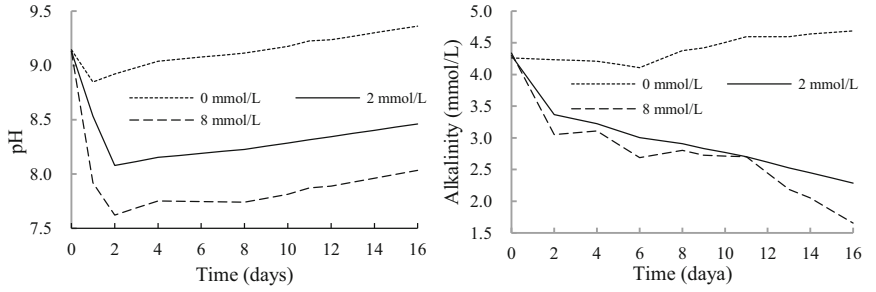


**Fig. 11.3** Changes of pH and alkaline after $CaCl_2$ fertilization (from Shentu et al. 2000b)

a short time and it is not suitable to be used as a water quality improver in salt-alkali ponds.

Application of $NaHCO_3$ to the pond can also reduce the pH of water, but it must be applied in high concentration, and it will reduce the buffer capacity of water (Shentu et al. 2000b). Calcium sulfate has also been used as an improver in high alkalinity and low hardness ponds.

Pote (1990) used aluminum sulfate [$Al_2(SO_4)_3 \cdot 14H_2O$] as an improver. Aluminum sulfate can release hydrogen ions by hydrolysis. However as aluminum can be easily precipitated in the form of $Al(OH)_3$ and $AlPO_4$, the total phosphorus and soluble reactive phosphorus in the water will be significantly reduced.

### 11.5.3 Water Quality Regulation by Filter-Feeder Fish in Salt-Alkali Ponds

Previous studies have shown that aquatic plant plantation in the salt-alkali ponds can reduce the alkalinity of water; however, the concentration of inorganic nitrogen and phytoplankton biomass in water is also reduced. The filter-feeders such as silver carp, bighead carp, and tilapia can feed on large plankton, and thus relieve the feeding pressure of the zooplankton on phytoplankton, increasing phytoplankton abundance, primary productivity in the pond (see Chap. 7 for details). The following will introduce a new inner net partitioned polyculture method of shrimp with tilapia.

#### 11.5.3.1 Inner Net Partitioned Polyculture of Shrimp and Tilapia

Polyculture of whiteleg shrimp with Nile tilapia is common to prevent the white spot disease of the shrimp in salt-alkali ponds. However, the system has three disadvantages. Firstly, the tilapia in the polyculture system will swoop feeding the relatively expensive shrimp feed, which contains higher protein content compared with the tilapia feed. Secondly, the tilapia can rapidly suppress and reduce zooplankton populations throughout the pond due to their high filter feeding capacity (Zhang et al. 1999a; Sun et al. 2010), thus blocking the food chain from phytoplankton to tilapia, affecting tilapia's indirect use of phytoplankton primary productivity and in turn affecting the growth of tilapia (Tian et al. 1997). Thirdly, tilapia may also prey on molting shrimp. To solve the above problems, we have developed the inner net partitioned polyculture of shrimp and tilapia in salt-alkali ponds.

Whiteleg shrimp and Nile tilapia are polycultured in inner net partitioned polyculture ponds (Fig. 11.4). The ponds (36 m × 14 m × 2 m) are divided into three parts by two nets, tilapia is stocked in the middle area of 7 m × 14 m to prevent the fish from competing for the high-value shrimp pellet and from preying on the zooplankton in other areas.

In a trial (Jie 2006), three ponds were stocked with shrimp only; three ponds were stocked with shrimp and tilapia without feeding the fish; the other three ponds were stocked with both shrimp and tilapia, and both were fed by formulated feed. Shrimp (0.01 ± 0.01 g) were stocked in ponds at a density of 45 ind./$m^2$ and fish (51.74 g ± 19.63 g) were stocked at a density of 51.6 g/$m^2$. During the 95 days of culture trial, there were no significant differences in dissolved oxygen and pH among

**Fig. 11.4** Inner net partitioned polyculture of shrimp and tilapia in ponds (from Dong 2015b). Left: Schematic sketch; Right: Actual photos

treatments, but the transparency of the shrimp monoculture pond was significantly lower than that of the other two treatments. The survival rate of shrimp in polyculture without feeding the fish was 48.6% and 23.7% higher than that of shrimp monoculture and polyculture with feeding the fish, respectively. In addition to the additional yield of tilapia, compared with the shrimp monoculture, the net yield of shrimp increased by 13.1% and 12.5%, respectively in the polyculture ponds.

#### 11.5.3.2 Effects of Tilapia on Phytoplankton Community

Compared with the common polyculture model of shrimp and tilapia, the inner partitioned polyculture system can improve the plankton community structure and in turn improve the growth of tilapia (Sun and Dong 2010; Sun et al. 2010). In fact, in the inner partitioned polyculture system, the areas where shrimp are cultured are zooplankton refuges. The average rotifer biomass is significantly higher in the farming waters with zooplankton refuge than the farming waters without refuge (Fig. 11.5).

The average phytoplankton biomass in waters with refuge is 101 mg/L, which is significantly lower than the waters without refuge (140 mg/L). In addition, the setting of the refuge can significantly increase the phytoplankton diversity. At the end of the trial, the average fish weight is 5.4 times higher in the waters with refuge than the waters without refuge (Table 11.7).

To make good use of primary productivity, it is important to maintain a certain amount of zooplankton biomass. The rotifers are prolific and are good food sources for tilapia, and can make better use of the phytoplankton in the water. The above

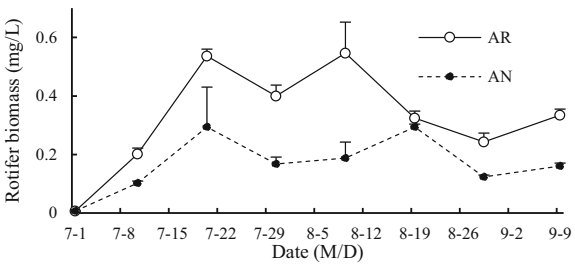


**Fig. 11.5** Rotifer biomass in the pond water (from Sun and Dong 2010). *AN* without zooplankton refuge, *AR* with zooplankton refuge

**Table 11.7** Growth of tilapia in the water with and without refuge (from Sun et al. 2010)

| Treatments | Stocking biomass of fish (kg/28 $m^2$) | Fish number | Average growth increment of fish (g) |
|---|---|---|---|
| With refuge (AR) | 5.05 ± 0.04 | 31.33 ± 0.33 | 23.5 ± 6.00 |
| Without refuge (AN) | 5.06 ± 0.03 | 31.33 ± 1.20 | 3.17 ± 4.19 |

study demonstrates that the zooplankton refuge, i.e., the inner partitioned polyculture system, is effective in increasing zooplankton biomass and thus increasing fish yield.

#### 11.5.3.3 Structural Optimization of Shrimp and Tilapia

In a 36-day study, 12 land-based enclosures (each 5 m × 6 m) were set in a salt-alkali pond with an average water depth of 1.3 m to find the optimal stocking structure of shrimp and tilapia with the highest energy conversion efficiency. All fish were cultured in net cages (1.2 m × 1.2 m × 0.7 m) inside the enclosures. The results showed that the fish had a significant effect on the biomass of phytoplankton (Table 11.8), and the transparency of the water with fish was significantly higher than that without fish. The transparency of the polyculture system with a medium stocking density of fish (P2) was the largest. As the stocking density of fish increased, the ratio of primary production to community respiration (*P/R*) increased.

The shrimp yield in P2 is 40.9 g/$m^2$, which is significantly higher than those of CO (25.8 g/$m^2$), P1 (27.7 g/$m^2$), and P3 (27.0 g/$m^2$). Shrimp in the P2 also had the highest individual weight gain, survival rate, and lowest feed conversion efficiency.

**Table 11.8** Ecological effects of inner net partitioned polyculture of tilapia with shrimp (from Jie 2006)

| Indicators | CO | P1 | P2 | P3 |
|---|---|---|---|---|
| Dissolved oxygen (mg/L) | $9.36 \pm 0.62^a$ | $8.82 \pm 0.30^b$ | $8.33 \pm 0.40^b$ | $8.02 \pm 0.70^b$ |
| Transparencies (cm) | $38 \pm 6^a$ | $42 \pm 6^b$ | $45 \pm 3^b$ | $42 \pm 8^b$ |
| Primary production/ community respiration | $1.06 \pm 0.24^a$ | $1.25 \pm 0.10^{ab}$ | $1.34 \pm 0.18^{ab}$ | $1.44 \pm 0.11^b$ |
| Photosynthetic energy input per unit net product | $80.59 \pm 12.89^a$ | $55.81 \pm 5.49^b$ | $29.24 \pm 3.67^c$ | $28.22 \pm 2.62^c$ |
| Biological energy input per unit net product | $24.62 \pm 1.42^a$ | $19.78 \pm 0.27^b$ | $12.95 \pm 1.10^c$ | $15.08 \pm 0.84^d$ |
| Total energy input per unit net product | $105.41 \pm 13^a$ | $81.27 \pm 5.54^b$ | $50.50 \pm 4.97^c$ | $57.26 \pm 4.90^c$ |

Note: Shrimp were stocked at 59 ind./$m^3$. Individual weight of the shrimp was 0.01 ± 0.01 g, and individual weight of tilapia was 139.68 ± 39.40 g. CO is control, without tilapia; P1. Tilapia 7 ind./$m^3$; P2. Tilapia 22 ind./$m^3$; P3. Tilapia 48 ind./$m^3$; Photosynthetic energy input for unit net product (kJ/fish or shrimp) = Photosynthetic input/Total net product; Biological energy input for unit net product (kJ/fish or shrimp) = Biological input/Total net product; Total energy input for unit net product (kJ/fish or shrimp) = Total energy input/Total net energy product

Net photosynthetic energy consumption per 1 g shrimp produced by CO treatment without tilapia was 80.59 kJ, which was significantly higher than those of the treatments with tilapia. The least biological energy input for unit net product and total energy input for unit net product occurred in P2, which were 12.95 kJ/g and 50.50 kJ/g, respectively.

The results of the above study show that the inner net partitioned polyculture of whiteleg shrimp with tilapia is effective in reducing the waste of shrimp feed fed by the tilapia and improving the survival of shrimp. In the medium fish stocking density, the shrimp yield is highest, individual weight gain is highest, the feed conversion efficiency is lowest, and ecological indicators are all at best conditions.

**Brief Summary**

1. The saline soils in the coastal area are mainly affected by seawater and are chloride type. The formations of waterlogged salt-alkali land are mainly due to the low topography, relatively high groundwater level, and long-time poor drainage of rainwater.
2. Pond-based aquaculture-agriculture system is a very efficient model for the exploitation of waterlogged salt-alkali land and waterlogged acidic saline-humid soil areas influenced by rhythmic ocean tides.
3. Inland waterlogged salt-alkali ponds are usually characterized by high alkalinity and high pH. $Ca^{2+}$ deficiency in salt-alkali ponds results in poor buffering capacity of the water. When there is strong photosynthesis, dramatically rising pH to a certain threshold value may stress the farmed aquatic animals.
4. The main composition of alkalinity that is toxic to farmed fish is $CO_3^{2-}$. The safety threshold of alkalinity for fish farming is about 10 meq/L.
5. The $K^+$ deficiency is often found in the groundwater of some salt-alkali land. KCl can be applied to the shrimp pond to increase the $K^+$ in water, and the $Na^+/K^+$(mol/mol) ratio should be regulated at about 40. The lower the salt content of the water, the more sensitive the farmed shrimp to the change in $Na^+/K^+$ ratio.
6. Increasing the concentration of $Ca^{2+}$ in calcium-deficient water can significantly improve the aquaculture benefits. The amount of $CaCl_2$ application is related to the salt content of the water, and more $CaCl_2$ should be applied in higher salt content water. When the salt content is 5 ppt, the $Ca^{2+}$ concentration should be kept above 44 mg/L; when the salt content is 15 ppt, the $Ca^{2+}$ should be kept above 87 mg/L; and when the salt content is 30 ppt, the $Ca^{2+}$ should be kept above 350 mg/L.
7. Delivering feeds, applying organic fertilizer and $CaCl_2$ can efficiently reduce the alkalinity and pH of aquaculture water.
8. Setting up zooplankton refuges in the filter-feeding fish pond, such as the inner net partitioned polyculture of whiteleg shrimp with tilapia, is an effective way to increase fish production by maintaining a certain amount of zooplankton in waters.